A New Traversal Method for Virtual Reality: Overcoming the Drawbacks of Commonly Accepted Methods

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1 Introduction

One of the biggest issues facing VR as a platform is the limitation of the user's physical space. Not everyone has a lab, empty warehouse, or open space in their home or office, and even if they do, the hardware also limits the physical space the user can take advantage of. For example, the HTC Vive hardware limits the play area to $12.5m^2$, assuming the user does not add additional lighthouses [16]. Fitting the entirety of the environment within few square meters is a strict limitation for many applications. A method of moving the user within a larger space is needed, but current methods come with a trade-off. Determining the best movement method for an application is necessary to ensure a proper experience for the user.

2 Keywords

Virtual Reality, Teleportation, Virtual Reality Sickness, Spatial Memory, Cognitive Mapping, Edit Blindness, HTC Vive, Virtual Reality Toolkit (VRTK)

3 Related Work

Related methods have focused on comparing and exploring different traversal methods in VR. A good example comes from Freedom Locomotion VR [3]. This game is a showcase demo of a virtual reality navigation system that allows a user to navigate a full scale virtual environment from within a small physical space. Freedom Locomotion VR's development goals were focused on reducing VR sickness, while allowing the user a high degree of freedom with regards to their movement. The program uses three locomotion systems: Controller Assisted On the Spot, Dash Step, and Blink Step. Controller Assisted On the Spot is a physical movement method that translates head bobbing and hand swinging into steps within the virtual environment. Dash Step and Blink Step are more traditional, teleportation-style systems that have been modified to help reduce

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the VR sickness felt by many users. Both make use of motion blur and interval-based movements, which some users claim prevents them from becoming ill.

Literature reviews comparing the cognitive aspects of different traversal methods exist, such as the investigation done by Boletsis et al. [1] and Karlson et al. [8]. Dr. Roy A. Ruddle at the University of Leeds conducted an investigation on users' ability to travel and gain mastery of different navigation systems [12].

4 Background

Common locomotion methods in VR:

- Point-and-click teleportation
- Artificial methods: sliding, dashing, and flying
- Physical methods: hand-swinging, head bobbing, and walk-in-place
- Teleportation via portal

Point-and-click teleportation is the most commonly adopted method of moving the user relative to the virtual environment. The abrupt shift in visual stimuli, referred to in film as a *mash cut*, can make some users sick; however, sickness responses from point-and-click teleportation are far less common than in other methods of movement. Point-and-click teleportation does not allow the user to maintain a constant view of their environment, or make use of translational cues, resulting in degraded spatial memory. It has been shown that for spatial tasks, users suffer a noticeable increase in error when using methods without translational components [11]. Another flaw of point-and-click teleportation is that it lacks the parity of position between the virtual and physical space, requiring the user to reposition themselves within their physical space to avoid stepping outside of the boundary. Point-and-click teleportation trades memory retention and awareness for user comfort. Not all users experience a reduction in memory or awareness, however, likely due to a well-known phenomenon referred to in the film industry as *edit blindness* [14].

Artificial interaction types such as sliding, dashing, and flying often lead to VR sickness, possibly due to the disconnect between the user's external sensory information (what they see and hear) and their vestibular system [9]. These movement paradigms are commonly well-received in fast-paced applications such as action games [17], where the user is more focused on specific objects rather than their entire field of view. In more relaxed settings with less fixation, users seem to receive these paradigms less favorably [7]. A notable exception to this trend is *Richie's Plank Experience*, where the flying mode seems to have been well accepted [18]. Artificial interaction methods can cause users to neglect their ability to freely walk within their space: the major focus of VR locomotion research since the "revival" in 2014 [1]. One thing artificial interaction methods do well is allow the user to maintain a continuous view of their environment. In film, abrupt cuts in visual stimuli have been shown to reduce cognitive representation [5], and recent research has shown that people react similarly to transitions in VR as they would in film [13]. Artificial methods trade user comfort for memory retention and awareness.

The last, somewhat-common alternative to point-and-click teleportation is physical-movement-based interpolation such as hand-swinging, walking in place, head bobbing, etc. These methods are less common, and how well they are received by users seems to vary wildly, as shown by user reviews of games on Steam that are centralized around these methods [20]. Some are received very well [4], and others very poorly [19].

Alternative methods of teleporting the user exist other than point-and-click teleportation, but are not mentioned in Boletsis's literature review of all movement types [1]. These methods often make use of a visible portal that needs to be touched or entered by the user, instantly transporting them to another location. Teleportation via portal does not seem to cause significant VR sickness, and a few well-received titles have made excellent use of the paradigm [2]. The effects of teleportation via portal on memory depend on two factors: the portal's location and its destination. Location refers to the entry point for the teleportation, and destination refers to the area that the user will arrive at once they enter the portal. The location and destination of a portal can be either fixed or dynamic. When teleportation via portal has a fixed location and fixed destination, the user's cognitive map becomes distorted [22], and this paradigm is not very useful for navigating complex environments, because it only shortens travel between predetermined locations, and one side of the portal must remain with the virtual environment mapped to the physical boundary, otherwise the user cannot access it. When teleportation via portal has a fixed location but a dynamic destination (or vis-versa), memory retention will likely be degraded due to the impossibility of accurately integrating the wormhole into the cognitive map [22].

Table 1: Portal Paradigms with Literary Examples

Portal Location	**Portal Destination**	**Literary Example**
Fixed	Fixed	Mario Bros: Warp Pipes [21]
Fixed	Dynamic	Stargate: SG1 Stargate Device [15]
Dynamic	Fixed	World of Warcraft: Hearthstone item [6]
Dynamic	Dynamic	Rick and Morty: Rick's portal gun [10]

5 Methodology

5.1 New Traversal Mechanism

We have begun testing a teleportation via portal implementation where both the location and destination are dynamic, and the user has full control over both.

The user pilots a remote camera using handheld controllers. This remote camera broadcasts its view to a stationary plane elsewhere in the scene, which the user can observe from a distance (Figure 1). When the user wants to go to another area in the environment, he pilots the remote camera to that location, using the broadcast plane as a visual indicator of the camera's location (Figure 2). Once the camera has arrived at the desired destination, the user physically steps into the broadcast plane. This causes the headset camera and remote camera's locations to be swapped, effectively transporting the user to the previous location of the remote camera (Figure 3). The broadcast plane will appear behind the user, allowing him to step directly backwards, or turn around and step through the plane again, to return to his previous location (Figure 4). While in the new area, the user may give commands and interact with the environment as normal, even piloting the camera to a third location.

We hypothesize that the constant visual stream provided by the broadcast plane will allow the user to build up spatial knowledge of the environment, similar to artificial methods, improving path integration. By abstracting the visual stream away from the headset and onto the plane, we are hoping to allow users' sensory information and expectations to remain in agreement, reducing the likelihood of experiencing VR sickness. Once the user becomes familiar with the system, we expect it to outperform point-and-click teleportation and artificial methods in both user comfort and cognitive mapping by providing a best of both worlds type experience.

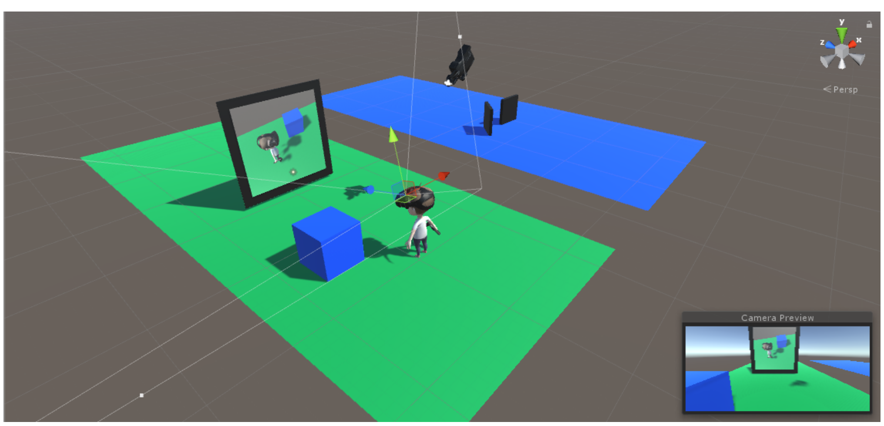

Fig. 1: The user stands in front of the broadcast plane. The remote camera shows the user standing next to the blue cube.

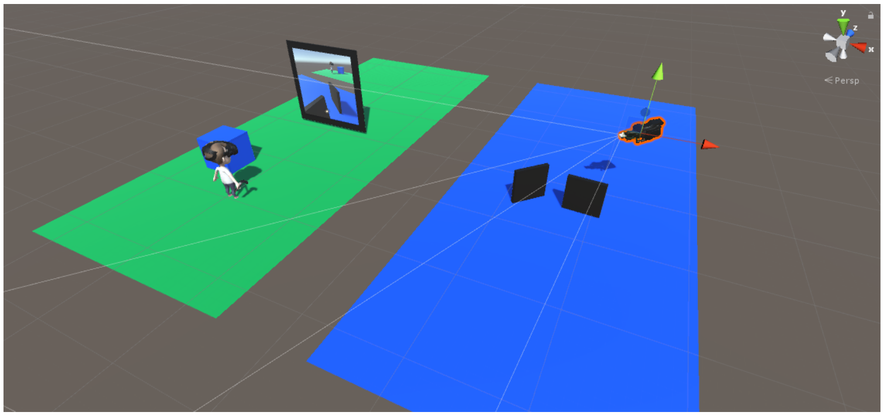

Fig. 2: The user pilots the remote camera to a new location. The remote camera shows the 2 slates on the blue plane, and the other location in the distance.

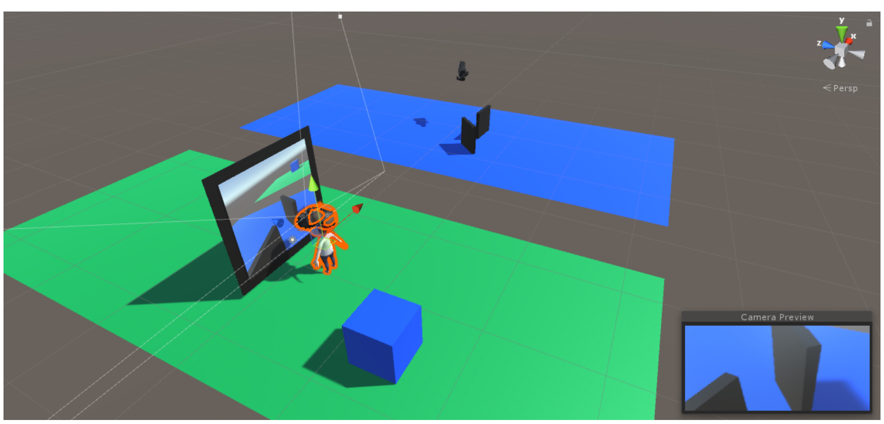

Fig. 3: The user physically steps through the broadcast plane. The user's view will seamlessly transition to the remote camera's location.

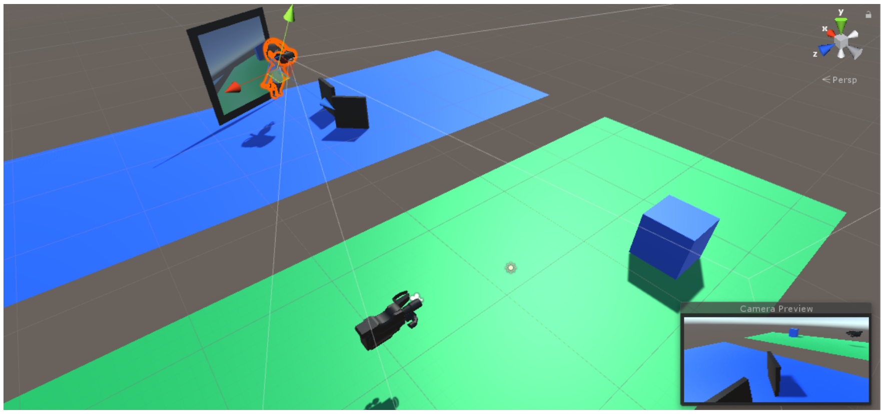

Fig. 4: The user has swapped positions with the remote camera. The broadcast plane has appeared behind the user for continued travel or easy returning.

Fig. 5: Video demonstration of the new method. (see Supplementary Material).

6 Upcoming User Study

An interior screenshot and floor plan of the virtual environment can be seen in Figure 6. It was modeled closely after the images of the environment shown in Ruddle et al. [12] in an attempt to reduce any effect the visual aspects of the environment might have on the results. The environment was made in Unity 2017.4. The HMD used will be a first generation HTC Vive Pro, with both controllers and two lighthouses. Participants' position and orientation in the virtual environment will be recorded for later analysis.

Fig. 6: The virtual environment for the upcoming user study.

The experiment will be done in three groups; one group for each movement method. The point-and-click teleportation group will use a traditional, trigger-operated method with a Bézier curve indicator from the VRTK library to control their movement. The artificial group will use the thumb-operated trackpad on the HTC Vive Pro controllers to control their movement. The teleportation via portal group will use the thumb-operated trackpad and menu buttons to control the movement of the camera and the broadcast portal.

6.1 Proposed Procedure

First, users will be introduced to the VR hardware and display by completing the Steam VR Tutorial, which explains the control layout and visual information displayed inside the HMD. Participants will then be asked to take a short VR sickness questionnaire before agreeing to continue the study. Then participants will be given a brief description of their movement paradigm, and allowed to test it an a large, empty virtual room for a few minutes. Participants will then be placed in the virtual environment described above, and given their task: locate eight murals within the room in a specific order, and touch them. Participants will complete this task 10 times, then complete a post-experiment VR sickness questionnaire identical to the first.

6.2 Proposed Analysis

Four aspects of participants' travel will be analyzed: time, accuracy, speed, and backtracking. This data will be manually extracted from the video footage of what is displayed to the user, as well as the footage of the user's location and actions from the perspective of the entire virtual environment.

Time will be measured from the first moment of purposeful user movement until the final image has received its trigger condition. Along with speed, time can be used as a partial measure of how confident the user is with the movement method, and we expect their time to decrease from trial to trial.

Accuracy will be measured both by correct sequence order and by collisions with scene objects. Comparing this value with speed will allow us to estimate a user's mastery of a movement method, and we expect accuracy to increase as the experiment progresses.

Speed will be measured as a ratio between idle and active user action. For the teleportation-via-portal group, idle time will be categorized as periods where neither the camera object nor the user's translational coordinates changed. For the other two groups, idle time will be categorized as periods where solely the user's translational coordinates do not change (standing still but looking around, aiming, etc). We expect individual's speed to increase as they become more comfortable with their prescribed movement method.

Backtracking will be measured by how often a user's path overlaps with itself, and by how often users spend moving away from (or at least no closer to) the next panel in the sequence. Over time, we expect backtracking to decrease if users can build an accurate cognitive map of the virtual environment.

7 Future Work

We are interested in seeing the effects that abstracted, continuous visual information has on the user while navigating their environment. During testing of the implementation, some users commented on the relative difficulty and higher learning curve of the new method compared to others. We hope this can be overcome with user mastery, otherwise these potential drawbacks may restrict the types of applications the new method could be integrated into.

We are hoping to implement seamless transitions into the paradigm before the upcoming user study. The current offset upon arrival at the new location may reduce the visual benefit and differences between the new method and point-and-click teleportation.

An HCI study comparing user's evaluation of the method under fast-paced conditions vs. less stressful stimuli would prove fruitful going forward. It's possible the method's somewhat cumbersome visuals would need to be adjusted or hidden, or perhaps it's simply not well suited for scenarios requiring fast reaction times and short response windows.

A psychological study with a more complex environment focused more exclusively on memory recall and retention might contribute to the body of work describing how visual stimuli affects human object permanence, as well as the updating and outdating processes of short term and working memory.

Comparing how different VR movement methods affect the severity of change blindness on users would be an interesting film study topic.

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